Speech Errors Before and After Osteotomy

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Abstract

This study aimed to investigate change in speech after surgical intervention (osteotomy) for a clinical population with malocclusion. Thirty Cantonese speaking adults with malocclusion were involved in the study. Speech data was collected using the Cantonese Osteotomy Deep Test for production of sibilants (/s/, /ʃ/, /ts/, /tsʰ/) pre-surgically, and at three and twelve months post-surgically. Perceptual analysis was then conducted with narrow transcription being made. The results of the study showed a statistically significant reduction in the number of post-surgery speech errors for subjects as a group with, however, individual differences found. The correlation between subjects' perception judgment and their speech performance was also discussed. The results of the study have clinical implications for speech intervention with the malocclusion population.

Introduction

In last decades, researchers have investigated both the speech problems related to dental and occlusal abnormalities and the effect of surgical intervention (osteotomy) on these speech problems (Cook & Sickels, 1986; Glass, Knapp & Bloomer, 1977; Laine, 1987, 1992; Lee, Whitehill, Ciocca & Samman, 2002; Ruscello, Tekieli, Jakomis, Vallino, 1987; Whitehill, Samman, Wong & Ormiston, 2001; Witzel, 1980). While most researchers found that dental and occlusal abnormalities had an effect on speech, there are still controversies over the effect of osteotomy on speech errors (Garber, Speidel & Marse, 1981; Lee et al., 2002; Ruscello et al., 1986).

Malocclusion is any deviation from normal dental or skeletal relationships and there exist different systems of classification (Ackerman & Proffitt, 1969, cited in Jablonski, 1992; Angle, 1907, cited in Dofka, 2000; Bjork, 1953). Angle's classification is standardized and the most commonly used system to classify malocclusion. This system refers to horizontal dental dimensions, i.e., the relationship between the first mandibular and maxillary molars.

For classification of vertical dental dimensions, i.e., the relationship between the maxillary and mandibular incisors, the Ackerman-Proffitt classification is used (Ackerman & Proffitt, 1969, cited in Jablonski, 1992). There are two variants under this classification: openbite and overbite. Appendix I shows definitions for different classes of malocclusion under Ackeman-Proffitt and Angle's classification.

Both abnormal horizontal and vertical dental relationships may have a deleterious effect on speech (Bowers, Tobey & Shaye, 1985; Laine, 1992; Ruscello et al., 1986; Witzel, 1981). While some studies suggested similarities of speech performance across different types of dentofacial abnormality (Vallino & Tompson, 1993, Whitehill, 2001), others have suggested a tendency for one type of dentofacial abnormality to have more severe impact on speech than the other (Laine, 1987, 1992; Ruscello et al, 1986; Vallino, 1990).

Laine (1987) found that mesial molar occlusion, mandibular overjet and lateral crossbite was related to misarticulation of the alveolar fricative /s/. Later, Laine (1992) also reported that incisal open bite combined with mesial occlusion was related to more severe misarticulation. Ruscello et al. (1986) found that their Group II (antero-posterior discrepancies of mandible greater than maxilla) and Group IV subjects (vertical maxillary excess) had higher mean error scores than Group I (antero-posterior discrepancies of maxilla greater than mandible) and Group III (asymmetry). However, only a few papers found statistically significant differences among the dentofacial groups on any speech measure (see review by Whitehill et al., 2001).

Most of speech errors observed in this population are in the form of distortions (Ruscello et al. 1986; Witzel, 1981). Sibilants have been found to be vulnerable for people with dental and occlusal abnormalities in both English and Cantonese (Dalston & Vag, 1984; Ruscello et al., 1986; Vallino, 1987; Whitehill et al., 2001). Among the sibilants, the major error for English speakers is /s/ (Witzel, 1981); and that for Cantonese is /f/ (Whitehill et al., 2001). Other error sounds found in English patients include bilabial and labiodental consonants (e.g., /b/, /d/). For Cantonese, one language-specific error pattern, substitution of [ts] for /s/, was noted in people with malocclusion (Whitehill et al., 2001).

Osteotomy is a bone incision introduced to surgically improve craniofacial abnormalities (Dofka, 2000). For severe malocclusion and with growth ceased, osteotomy is the only means to correct malocclusion (Fonseca, 2000). The nature of procedure selected for malocclusion patients depends on the extent of the maxillary deformity, the proportion of affected maxilla, the type of malocclusion and the degree of which other facial structures are involved (Peterson-Falzone, 2000).

Previous studies

Researchers have investigated the change in speech before and after osteotomy using both acoustics and perceptual measures. Discrepant results were found. A number of researchers found no positive change in speech after orthognathic surgery. In Garber et al. (1981), the six Class III subjects showed an increase in speech errors in perceptual measurement which returned to pre-operation ratings 12 months post-operatively. Goodstein, Cooper & Wallace (1974) studied the speech of five patients at word, sentence and paragraph level and found that there was no significant change in speech pattern perceptually following osteotomy. Dalston & Vag (1984) used both perceptual and acoustic measures in their study. They found that, as a group, 40 patients showed no significant shift in error rate.

Some researchers, however, found that there were positive changes in speech after surgery. Some of them used perceptual measures in their studies. Turvey (1976) studied nine subjects with anterior open bite and reported an improvement for interdental lisp and aberrant tongue habits after surgery. In Ruscello et al. (1986), 20 Class I to IV patients showed improvement in speech post-surgically on all perceptual variables assessed. Ruscello and colleagues also reported subjects' perception of speech performance. Before surgery, none of the patients with speech problem perceived that they had speech problem. After osteotomy, most of the subjects perceived a positive change in their speech.

Witzel (1981) studied 42 patients with Class II and III malocclusion before, six months, and 12 months after osteotomy. The number of speech errors was reduced after surgery. However, Witzel did not provide a description of the errors.

Vallino (1987) investigated speech changes in 34 patients at four periods (before, three months after, six months after and 12 months after the surgery). While errors in production of bilabial and tip-alveolar sounds were eliminated after osteotomy, distortion errors in sibilants remained (although the frequency of errors was reduced by more than 50%).

Some studies used acoustic measures instead. Yamamoto, Imai & Umeda (1995) studied the fricative production of 14 patients with Class III malocclusion before and six months after osteotomy. They concluded that spectral patterns changed and became more similar to normal subjects. However, no statistical analysis was carried out in their study. Wakumoto, Isaacson, Friel, Suzuki, Gibbon, Nixon, Hardcastle, & Michi (1996) used acoustic measures to investigate changes in /s/ production of five Class II and III patients before and 6 months after the surgery. They found all five patients improved and the change in articulatory place evaluated by using electropalatography was sustained six months after osteotomy.

Some studies used perceptual measures together with acoustic measures. Bowers et al. (1985) examined the formant frequency changes of speech for five Class II and III patients before and after surgery (after the removal of orthodontic appliances). The speech of all subjects in their study were perceptually normal pre- and post-operatively and the acoustic measures revealed that there might be a reorganization of speech patterns after surgery.

Lee et al. (2002) studied /s/ production in nine patients with Class III malocclusion before, three months and 12 months after the osteotomy. Relapse for one patient was observed from perceptual analysis, while another patient who showed no error pre-osteotomy exhibited speech error after the osteotomy. For acoustic analysis, 'relapse' was also noticed. The patients as a group showed positive, then negative change in two acoustic variables (spectral peaks I and II). The findings by Lee and colleagues indicated that the improvement in speech might not be sustained for some patients.

Discrepancies among findings are due to difference in methodologies, including the small number of subjects in some studies and varied duration of follow-up after surgery (six to 12 months). Besides, different parameters in speech evaluation also matter. While some used perceptual measures, others used acoustic measures and some used both. Even among those who used acoustic measures, different acoustic variables and different instruments were involved.

For perceptual measures, most of the studies used a limited analysis of articulation. For instance, Dalston (1984) analyzed the speech errors in broad transcription categories (omissions, substitutions and distortions). No further analysis for distortion error pattern was made. In the studies by Witzel and colleagues (1980) and Goodstein et al. (1974), they did not provide a description of speech errors. The limited analysis of articulation errors failed to reflect the full picture of the speech characteristics of the speech of this population (Whitehill et al., 2001).

Research Questions

The research questions for this study were:

1. Will the speech (particularly sibilants) of patients with malocclusion change after osteotomy using detailed perceptual analysis?
2. Will there be any relapse in articulatory accuracy one year post-operation?
3. Which phonemes are more amenable to surgical treatment?
4. Will there be any change in speech error patterns following osteotomy?
5. Will the subjects recognize their speech problem or any change in their speech after surgery?

Expectations

1. There will be an improvement in production of sibilants for this population after osteotomy in terms of (a) number of error phonemes and (b) frequency of errors (Vallino, 1987; Turvey, Journot, & Epker, 1976)
2. If there is an improvement in production of sibilants, it will be a long-term effect (present in 12 months post-operatively) for at least some of the subjects (Turvey et al. 1976; Vallino, 1987; Lee et al., 2002).

3. /s/ sound is the sibilant sound that most likely to remain erroneous in speakers even after osteotomy (Vallino, 1987). A similar result was expected for /s/ sound production in this study.
4. There would be changes in error patterns (e.g. distortion errors proportionally increase post-surgically) among different time periods (Vallino, 1987).

Methodology

The study was a follow-up study of the subjects investigated by Whitehill et al. (2001). To allow comparison with pre-surgery data (Whitehill et al., 2001), the post-surgery data collection and analysis followed similar procedures as in Whitehill and colleagues' project.

Materials and Procedures

The dentofacial examination was conducted before and after osteotomy by a surgical staff member, according to the standard protocol used in the Oral and Maxillofacial Surgery Unit, University of Hong Kong. Speech assessment included evaluation of voice, resonance, and articulation.

For this study, only the articulation of the subjects will be investigated, as it was the most controversial aspect of speech in the malocclusion population. Vallino (1990) commented that orthognathic defects mainly affected articulation, rather than resonance or voice disorders. Perceptual analysis was applied in this study to investigate how speech change perceptually after osteotomy.

The assessment was conducted in a quiet room. Speech samples were both audio- and videorecorded. For audiorecording, a Sony TCD-D3 Digital tape recorder and a Sony ECM-909 microphone was maintained at a mouth to microphone distance of 10 cm. A JVC GR-AX7E videocamera was used for videorecording and it was positioned to allow maximum view of the mouth during recording.

Two native Cantonese speaking speech evaluators (not the author of this dissertation) made judgments "live" and independently. Transcriptions and coding were compared on a point-to-point basis. In case of any discrepancies, they were resolved by reviewing the audio- and video record together with a speech-language pathologist with over ten years experience with speech disorders associated with dentofacial abnormalities. The consensus model was introduced to ensure inclusion of all data.

Articulation was assessed using two word lists. Single word stimuli are considered more sensitive in identifying speech errors than sentence level tasks (Ruscello et al., 1986). The single word portion of Cantonese Segmental Phonology Test (CSPT) (So, 1993) and the Cantonese Osteotomy Deep Test (CODT) (Whitehill, 1995) were used.

The CODT contains the 6 initial phonemes that are most vulnerable in this population: /s/, /ts/, /ts^h/, /f/, /p/ and /p^h/ (Witzel, 1981), each sampled 20 times in varied phonetic contexts (CV or CVC structures). CSPT was an articulation test that contained 31 items for the single word portion. It included all the Cantonese phonemes and tones. Whitehill et al. (2001) found no significant correlation between CSPT and CODT in terms of the number of errors identified.

Both word lists were read aloud by the subjects. For CSPT, only the number of errors was recorded. For CODT, a narrow transcription was made. The total correct score was documented and errors were classified based on Vallino's classification system (1987). The system was adopted from Vallino's study (1987) which involved detail analysis on articulation errors. Errors were first categorized into broad categories of omission, substitution, or distortion. Distortion errors were classified as auditory, visual or both. Then they were further categorized into subtypes according to Vallino (1987): frontal distortion type I, frontal distortion type II, dentalization, lateralization, whistling, mandibular movement or labiodentalization. One more category 'Other' was added for errors that could not be classified into the previous categories. Referring to Whitehill et al. (2001), they identified errors of frication, weak production and bilabial fricative and classified them as Category VIII 'other'. Please refer to Appendix II for distortion error classification.

The speech examination was carried out before osteotomy, three months after and 12 months after osteotomy. The time period of three months post-operation was chosen as the greatest change in articulation was expected to occur (Vallino, 1987). The time period of 12 months was chosen to study the long-term effect of the osteotomy.

In addition, to supplement objective assessment information as suggested by Ruscello et al. (1989), subjects' perception on their speech was collected using questionnaire which was conducted pre-surgery, three months and 12 months post-surgery.

Statistical analysis

Descriptive statistics of mean and standard deviation were calculated for articulation scores. Parametric statistical test was used to analyze the speech to determine if there are significant differences in speech errors among pre-operation, three months after operation and 12 months after operation. A two-way repeated measures analysis of variance (ANOVA) was used to study the changes in the four sibilants: /s/, /ts/, /ts^h/, /f/. As the basic assumptions in ANOVA were violated, a multivariate approach (F test with Pillai-Bartlett Trace) was introduced. Post-hoc tests (Tukey's test) were used to examine the individual phoneme changes pre and post osteotomy, or if the number of errors in two specific time periods were significantly different. For each test, the level of significance was set at $p \leq .05$.

For analysis of the correlation between subjects' perception and their speech performance reflected in articulation test, a nonparametric statistical test of phi coefficient was introduced as the data was in nominal scale.

Subjects

The 30 subjects had all participated in Whitehill et al. (2001) project. They were Cantonese-speaking adults presenting consecutively for orthognathic surgical correction of dentofacial abnormality in Department of Oral and Maxillofacial Surgery, Prince Philip Dental Hospital, University of Hong Kong. The surgeries they received were selected according to their individual needs. These included LeFort I, LeFort II, Wunderer, Schuchardt, Hofer, Mandibular step, Subsigmoid, Sagittal split and Genioplasty. Appendix III provides a description of the surgical procedures.

The age of subjects ranged from 15 to 40, with a mean age of 24.90 years (SD = 6.48). There were 14 males and 16 females. All were native Cantonese speakers. They had hearing of 25 dB HL or better in at least one ear, as determined by audiometric testing at octave frequencies of 250 Hz to 8000 Hz. None of the subjects had cleft palate or other orofacial syndromes. None of them had received speech therapy. All of them participated in pre-surgery, three month post-surgery, and 12 month post-surgery data collection. Details are shown in Table 1.

Table 1. Subject information before and after surgery.

Sub	Sex	Age	Surgery[1]	Pre-surgical					Post-surgical	
				Complaint[2]	Speech error[3]	Occ type	Overjet (mm)	Openbite[4] (mm)	Occ type	Overjet (mm)
1.	F	35	1,5	SK, M	No	III	-3.4	4.1	I	+2.0
2.	M	40	1,6	SK, SP, M	Yes	III	-8.0	--	I	+4.0
3.	F	20	1,5	SK, M	Yes	III	-8.0	--	I	+2.0
4.	M	25	1,5,8,9	D, M	Yes	II	+10.9	2.9	I	+3.0
5.	M	16	3,4,5,9	SK, D	Yes	II	+5.1	--	I	+3.0
6.	M	24	2,6	SK	Yes	III	0.0	--	I	+2.0
7.	F	19	1,5	SP, M	Yes	I	-4.0	5.0	I	+4.0
8.	F	28	8	M	No	II	+12.0	--	I	+2.0
9.	F	23	5,8,9	SK, SP, M	Yes	II	+2.0	--	I	+2.0
10.	F	25	1,5,8	SK, D	Yes	II	+5.4	--	I	+3.0
11.	M	16	1,5,9	D	Yes	II	+3.0	--	I	+4.0
12.	F	16	1,5	SK	Yes	II	+7.0	--	I	+4.0
13.	M	29	1,5,7	D, SP, M	Yes	III	-6.0	--	I	+5.0
14.	M	25	1,7	SK	Yes	I	+1.1	1.0	I	+4.0
15.	M	25	1,6	D	No	III	-4.0	--	I	+3.0
16.	F	22	1,7	SK, D, SP, M	No	III	-4.6	1.0	I	+1.0
17.	F	33	1,5,9	MT	No	I	+1.2	--	I	+4.0
18.	F	18	1,5,8,9	D	Yes	II	+11.2	--	I	+2.0
19.	F	15	1,7,8	SK	No	II	+10.9	--	II	+8.0
20.	M	29	1,5,7	M	Yes	III	-8.5	4.4	III	-2.0

Table 1. (continued)

Sub	Sex	Age	Surgery[2]	Pre-surgical					Post-surgical	
				Complaint[3]	Speech error[4]	Occ Type	Overjet (mm)	Openbite[5] (mm)	Occ type	Overjet (mm)
21.	M	34	7,9	T, A	Yes	III	-4.0	--	I	+3.0
22.	M	20	1,6	SK, M	Yes	III	-3.2	--	I	+3.0
23.	F	21	1,7	D, S	Yes	III	-11.1	--	I	+4.0
24.	M	27	1,5	D, M	Yes	III	-2.4	1.2	I	+3.0
25.	F	27	1,5,8,9	D	Yes	II	+6.2	--	I	+4.0
26.	M	32	1,6	SK, M	No	III	-9.2	2.7	I	+4.0
27.	F	21	1,5	SK, M	No	III	-8.1	--	I	+4.0
28.	F	28	1,5,7	M	Yes	III	-2.9	3.0	I	+3.0
29.	F	35	1,5,9	M	Yes	II	+5.3	4.2	I	+3.0
30.	F	21	1,5	D	No	I	+3.5	--	I	+4.0

Note.

1. The headings were coded as follows: Subject (Sub), Occlusion type (Occ)
2. The surgical types were coded as follows: LeFort I (1), LeFort II (2), Wunderer (3), Schuchardt (4), Hofer (5), Mandibular step (6), Subsigmoid (7), Sagittal split (8) and Genioplasty (9).
3. For presenting complaint, patient responses were coded as follows: asthetic skeletal (SK), aesthetic dental (D), speech (SP), mastication (M), temporomandibular joint (TMJ), pain (T) and asymmetry.
4. For speech errors before surgery, it referred to speech errors under Cantonese Sibilant Test (Whitehill, 1995).
5. None of the patients had openbite after surgery

Results

The result of CODT for each subject was analyzed. A narrow transcription was made and errors were classified according to Vallino's system (1987) as mentioned before.

Number of errors

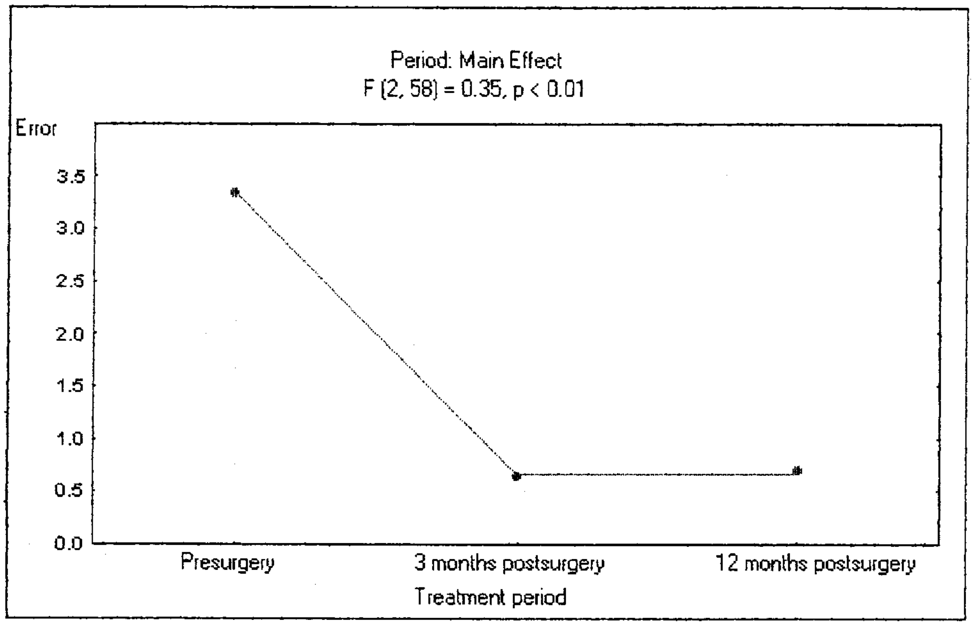
When considering the thirty subjects as a group, the total number of errors (out of 120 trials for each subject) greatly reduced three months post-surgery but slightly increased 12 months post-surgery. Table 2 shows changes in the number of errors across time. Mean, range and standard deviation (SD) reduced three months post-surgery, indicating a reduction in the discrepancy in terms of number of errors among the subjects. A slight increase in mean and SD 12 months post-surgery was noticed as compared to three months post-surgery. It reflected a slight increase in number of errors for subjects, while the range remained the same as three months post-surgery.

Table 2. Number of errors for subjects pre-surgery, three months and 12 months post-surgery.

Treatment period	Total	Mean	Range	SD
Pre-surgery	400	13.33	0-52	14.70
3 months post-surgery	77	2.57	0-20	5.72
12 months post-surgery	83	2.77	0-20	5.79

A two-way repeated measures analysis of variance (ANOVA) was used to study changes in the articulation of the four sibilants (/s/, /f/, /ts/, /tsʰ/) among the subjects. Since the homogeneity of variance has been violation, a multivariate approach (F test with Pillai-Bartlett Trace) has been introduced. The two factors taken into consideration were number of errors for sibilants production and the three periods (pre-surgery, three months post surgery and 12 months post surgery. Results showed that there was significant main effect of period (F (2,58) =0.34; $p < 0.01$). The main effect of period is shown in Figure 1. Significant main effect of sibilants was also found (F (3, 87) =0.45; $p < 0.001$). However, the interaction effect of period x sibilant was insignificant (F (6, 174) = 1.65; $p > 0.05$).

Figure 1. The main effect for treatment period.



A post hoc analysis using a Tukey HSD test revealed that the performance between pre-surgery and three months post surgery was statistically significant ($p < 0.01$). However, the performance between three months post surgery and 12 months post surgery was not statistically significant ($p > 0.05$).

The Tukey HSD test was also used to study the effect of surgery on individual sibilants. A statistically significant difference was found for the number of errors for /ʃ/ ($p <$ 0.01) and for /s/ ($p < 0.05$) before and after surgery (both three months and 12 months). No statistically significant differences were found for number of errors before and after surgery for /ts/ and /ts^h/ ($p > 0.05$). See Table 3, 4 and 5 in Appendix IV for summaries of statistical results.

As we consider individual changes, a similar picture was noted. Before surgery, nine out of 30 subjects had no speech errors. When comparing the data between pre-surgery and three months post-surgery, seven subjects who had no speech errors pre-surgically had no change in their articulation. 19 subjects showed improved articulation with a reduced number of speech errors after surgery. Out of these 19 subjects, ten showed no deterioration in their articulation, three showed improvement in articulation (further reduction in number of errors), while six showed slight deterioration 12 months after surgery.

On the other hand, four subjects showed deterioration in their articulation at three months post-surgery. Two of them had no articulation error before the surgery. All of the four subjects showed no articulation error 12 months post-surgery.

Among the 30 subjects, nine had articulation errors one year after surgery. Six of them had articulation error in /f/, two had error in /ts^h/ and one had error in both /f/ and /s/. For detail description of subjects with speech errors pre-surgery, three months post-surgery and 12 months post-surgery, please refer to Table 6 in Appendix V.

Change in error pattern

Table 7 shows the change in error types in broad categories and in distortion types. Distortion errors took up a larger portion of total speech errors than substitution errors across time.

Table 7. Change in error types and distortion types.

	Substitution	**Distortion**	**Subtypes of distortion errors**		
			A	V	A+V
Pre-operation	1.00%	99.00%	61.11%	35.60%	3.28%
	(4/400)	(396/400)	(242/396)	(141/396)	(13/396)
3 months post-operation	3.90%	96.10%	100.00%	--	--
	(3/77)	(74/77)	(74/74)		
12 months post-operation	1.20%	98.80%	100.00%	--	--
	(1/83)	(82/83)	(82/82)		

Note. The headings were coded as follows: Auditory (A) and Visual (V).

For substitution errors, it only occurred in production of /s/ and /tsʰ/. While one subject substituted /tsʰ/ by [ts], a number of subjects substituted /s/ by affricates (either [ts] or [tsʰ]). The number of substitution errors reduced consistently after surgery (both post three months and 12 months). However, its reduction rate was slow when compared with distortion errors. It led to a slight increase in the proportion it took in total number of errors three months after surgery.

In terms of distortion types, all visual distortion errors (V) and auditory plus visual (AV) were eliminated after the operation. Only auditory errors (A) existed post-operation.

For the nature of distortion, figures 2 -5 show the change in distortion pattern for sibilants across time. Please refer to Table 8 in Appendix VI for summary table of the change in distortion pattern.

Figure 2. Distortion pattern for /s/ pre-surgery, post three months and post 12 months.

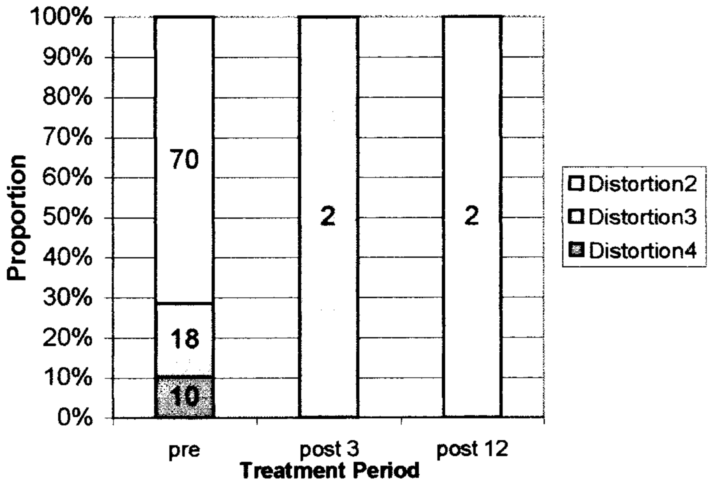


Figure 3. Distortion pattern for /f/ pre-surgery, post three months and post 12 months.

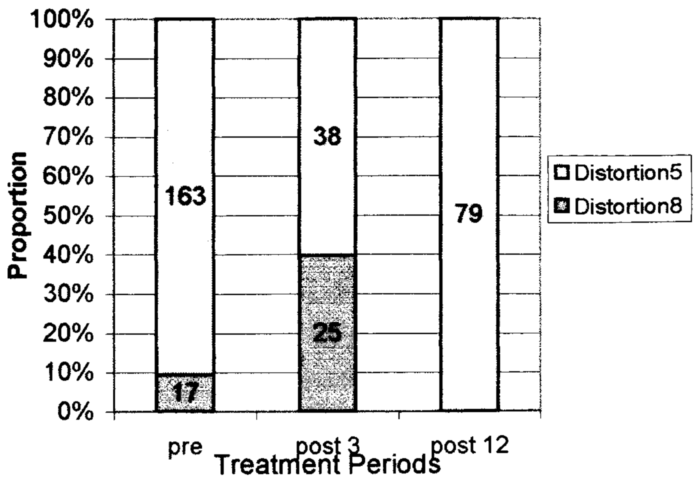


Figure 4. Distortion pattern for /ts/ pre-surgery, post three months and post 12 months.

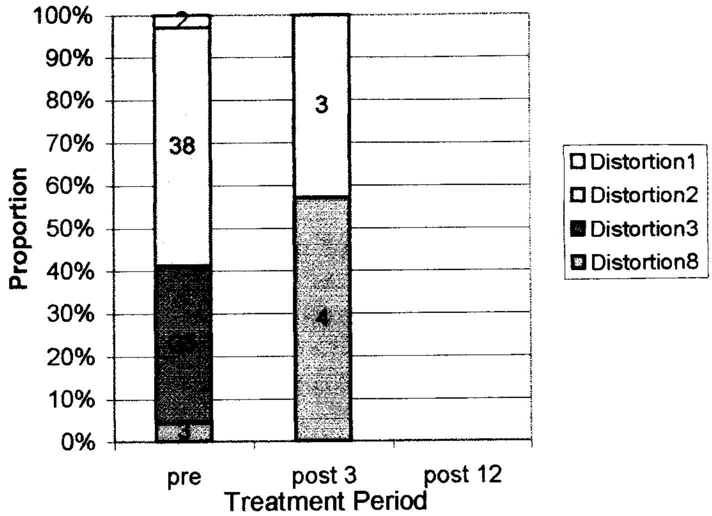
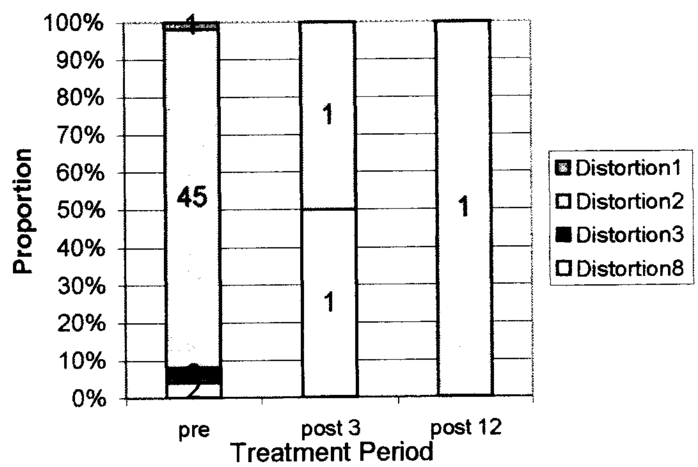


Figure 5. Distortion pattern for /ts^h/ pre-surgery, post three months and post 12 months.



There was a change in the proportion of different distortion error nature under Vallino's system (1987). For instance, distortion error type V (whistling) for /f/ took up a smaller proportion in three months after surgery, reducing from 90.50% to 60.30% of the errors. However, it increased in its proportion in one year after the surgery. All the errors were distortion error type V. All the four sibilants showed changes in the proportion of distortion error types. At one year post-operation, distortion error types I, III, IV and VIII were eliminated. Only distortion type II and V were present.

Regarding individual subjects, however, seven subjects showed no change in terms of nature of distortion error they had. Only four subjects showed changes, as shown in table 9. Among these four subjects, Subjects 5 and 22 showed changes in the distortion type (e.g., changed from frontal distortion type II to dentalization). Subject 23 showed changes in the type of error (e.g., from distortion to substitution). Subject 20 showed changes in both distortion error nature and in terms of type of error.

Table 9. Error pattern for individual subjects.

Subject	Pre-surgery	Post 3 months	Post 12 months
5.	/f/ → [f^{s}] (Da, Type VIII)	/f/→ [f*] (Da, Type V)	N/A
20.	/s/→ [s*] (Dav, Type II).	/s/ → [s̪] (Da, Type III); /s/→ [ts] (S)	N/A
22.	/ts/ → [ts*] (Da, Type II)	/ts/→ [ts^{s}] (Da, Type VIII)	N/A
23.	/ts^{h}/→ [ts*] (Dav, Type II)	N/A	/ts^{h}/→ [ts] (S)

Note. The types of errors were coded as follows: substitution (S), distortion (D). Distortion types were coded as follows: auditory (a), visual (v).

Subjects' perception of speech errors

Pre-surgery articulation errors were identified in 21 subjects, with 71.42% of them (15/21) perceived that they had speech disorder. For the nine subjects with no pre-surgical speech error, only 55.56% of them (5/9) thought that they had no speech disorder. Statistical measurement of Phi coefficient ϕ was used to study the correlation between subjects' perception and speech error reported in CODT. The relationship between subjects' perception and speech error was not statistically significant ($\phi^2 = 0.01, p > 0.05$).

Three months after osteotomy, seven subjects who had no change in number of speech errors, six out of them perceived no change in their speech performance. 23 subjects had change in speech in terms of number of speech error. Only 10 subjects (43.48%) noticed a change in their speech. Phi coefficient ϕ indicated a statistically significant correlation between subjects' perception and speech change three months post-surgically ($\phi^2 = 0.16$, $p < 0.05$).

After one year post-operation, 16 showed no change in their speech performance, ten of them did not perceive a change in speech. For the subjects with change in articulation, only 21.43% (3/14) perceived change in their speech performance. The Phi coefficient ϕ found a statistically significant correlation between subjects' perception and speech change ($\phi^2 = 0.22$, $p < 0.05$).

Discussion

The aim of the study was to investigate speech change (particularly sibilants) of people with malocclusion after osteotomy using detailed perceptual analysis. Information on their speech performance was collected and analyzed pre-operation, three months post-operation and 12 months post-operation.

Total number of errors

Consistent with some studies in English speaking population (Bowers et al., 1985; Ruscello et al., 1986; Turvey, 1976; Witzel, 1981; Vallino, 1987), the finding in this study showed that, overall, osteotomy resulted in improvement in articulation. It was a spontaneous change in articulation, with no speech therapy involved for all the subjects either pre- or post-surgery. The statistically significant improvement in articulation from pre-operation to three months post operation was agreed with Vallino (1987)'s claim that the greatest change in articulation was expected to occur at three months post-operation. As a group, the subjects did not have a significant change in their articulation performance between three months post-operation and 12 months post-operation. That is, there was a long-term effect for the osteotomy on articulation performance.

When we investigated individual cases, however, a discrepant picture was noticed. Some subjects showed a negative adaptation to the structural change in their oral cavity. Four subjects had articulation error three months after surgery even though two of them had accurate production before the surgery. All of them had no accurate articulation error one year after the surgery. Their performance was similar to studies in Ruscello et al. (1986) which reported deterioration in speech shortly after the operation.

However, one subject had accurate production pre-surgery and three months post-surgery but had deteriorated when reviewed one year post-surgery. The phenomenon observed in this patient was not related to structural relapse or adaptation problem alone, as he had no error pre-surgery and three months post-surgically. It was not found in previous studies (Turvey, 1976; Ruscello et al., 1986; Witzel, 1981; Vallino, 1987; Yamamoto, Imai & Umeda, 1995; Wakumoto et al., 1996). One possible explanation might be that the subject had structural relapse one year after surgery and adaptation problems to it, resulting in an increase in the number of speech errors. Since no data on post-surgical dentofacial measures was taken one year after surgery, it was unknown whether the deterioration in speech was related to structural relapse. Further investigation is needed for an explanation for the change in speech performance for this subject.

Six patients showed improved articulation at three months post-surgery which deteriorated by 12 months post-surgery. This phenomenon was also present in the past studies (Turvey et al., 1976; Lee et al., 2001). Turvey et al. (1976) also reported a similar case in their study. Their patient R.N. had improvement in speech three months after surgery, but showed deterioration at 12 months after surgery. They proposed that this patient had inappropriate postoperative retention which resulted in deterioration in speech. Again, it was unknown whether the deterioration in speech was related to structural relapse in this study.

Zajac (2002), discussing the results of Lee et al. (2002), also argued that after orthognathic surgery patients tried to maintain the acoustic-perceptual constancy of previously learnt speech targets. He suggested that there was a "negative articulatory reorganization", that is, a return to pre-surgery articulation patterns (Zajac, 2002). Though there was no previous study on this topic, the findings from bite-block studies might give us some insights to this area as it was a phenomenon opposite to negative articulatory reorganization.

In bite-block studies, subjects had a bite-block between their teeth to fix the mandible, and their speech with bite-block was analyzed. It was found that the subjects showed positive and spontaneous compensation in speaking with the bite-block (Lindblom, Lubker & Gay, 1979). They tended to adjust to a bite-block to preserve the perceptual constancy of previously acquired speech target.

Different from bite-block phenomenon, negative articulatory reorganization was a phenomenon that patients undergoing osteotomy tried to maintain the perceptual constancy of a previously acquired (deviant) speech target. While subjects in bite-block studies tried to maintain the previously correct speech production, some patients with osteotomy attempted to retrieve the previously deviant speech target. Both phenomena were related to a mechanism suggested by Lindblom et al. (1979).

Lindblom et al. (1979) have proposed a central predictive simulation mechanism, modified from Fairbanks's model (1954). They proposed that there are two levels of feedback loops, a central and a peripheral loop. The central loop allows the speech production system to transform the specified sensory goal into a simulated motor command. The mechanism predicts the required motor signals before they are executed, allowing compensation before the execution of the motor command.

Referring to the model, both tactile feedback and proprioceptive feedback will change after osteotomy, as in the bite-block phenomenon. The change in feedback will be sent to the central loop, with compensation made to produce motor signals similar to those before surgery. Though Lindblom et al.'s model could explain the bite-block phenomenon, more investigation into the feedback mechanism is needed for explaining the relapse after osteotomy which is a long-term issue compared to bite-block perturbation.

Changes in error sibilants

In terms of types of distortion, all visual distortion (V) errors were eliminated after the operation. Auditory plus visual (AV) errors were also eliminated. Only auditory errors (A) existed post-operation, which was different from Vallino's study, where all the three types existed post-surgically and visual plus auditory errors took up the largest proportion.

A more detailed analysis on the error revealed that the labiodental fricative /f/ was the sibilant that was most resistant to surgical treatment. It presented an increasing proportion of errors compared with other sibilants (increasing from 45.00% to 81.80% at three months post-surgery, and then to 95.20% of the errors at 12 months post-surgery). It was different with Vallino's finding that alveolar fricatives /s/ and /z/ were the most resistant. Indeed, the major error in sibilants for malocclusion group for English speakers is /s/ and that for Cantonese is /f/ (Witzel, 1981; Whitehill et al., 2001). This phenomenon exists even after the surgical intervention.

For other sibilants, errors in /ts/ were completely eliminated one year post-surgically. For /s/ and /ts^h/, only two patients had articulation errors occasionally (4 errors).

As we referred to the nature of distortion, the investigation into individual cases provided a clearer picture on changes. Only four patients showed changes in the nature of distortion error. However, no particular trend of changes in nature was identified among the four subjects.

Occlusion status and speech performance

After osteotomy, out of 30 subjects, 28 had occlusion type I with no openbite. The surgery did not improve two subjects (Subject 19 and 20) to normal occlusion status in terms of horizontal and vertical dental relationship.

Though Subject 19 had Class II malocclusion and overbite, she had no speech error before and after osteotomy. She was well adjusted to her malocclusion status and hence had no speech errors throughout the study.

Subject 20 had speech errors before and three months after surgery. No speech error was found one year post-surgery. His improvement in speech error was related to the improvement in vertical dental relationship (no openbite) even though he still had class III malocclusion.

Subjects' perception of speech errors

As a group, subjects' perception of speech disorder pre-surgically was not significantly correlated with speech errors detected in articulation test. While some subjects were unaware their speech problem, some wrongly perceived that they had speech problem.

Results of this study partly agreed with Ruscello et al. (1989) that some patients with malocclusion were unaware of their speech problem. Ruscello and colleagues found that none of the patients with pre-surgical speech errors perceived that they had speech problem. However, in this study, about 70% of patients with speech errors perceived that they had speech problems. One explanation for different findings was that on average subjects in our study exhibited more speech errors (13.33) compared with Ruscello et al's studies (5.72). Subjects in our studies were more aware of their speech problem as they had comparatively more speech errors.

Similar to Ruscello et al. (1989), subjects undergoing osteotomy were aware of their changes in speech post-surgically. Their perception of change in speech was significantly correlated with change in number of speech errors they exhibited post-surgically. Subjects' perception supplemented articulation test results and it could serve as a measure of change in speech performance pre- and post-surgery from patient's perspective.

Further research

In the study, data on structural status was not collected consistently after osteotomy. As structural relapse was suspected for an increase in speech error for some patients, data for vertical and horizontal dental relationship is needed for further investigation.

The post-surgical questionnaire used in the study mainly focused on subjects' perception of any change in speech. Direction of change in speech (improve or deteriorate) was not specified in the questionnaire. Further study on speech change after osteotomy could include a more detailed questionnaire to allow further investigation of the relationship between patient's perception of speech change and articulation measurements.

Clinical implication

The current study provided information about speech change after osteotomy. The results from the project had implications for the management of malocclusion. It reflected the efficacy of introducing surgical procedures to improve speech. While a positive effect on speech production was noticed, some subjects still had articulation error post-surgically. Speech intervention was recommended after osteotomy, instead of pre-surgically. Besides, as fricative /f/ was the most vulnerable sibilant in this population, speech training post-operation might be needed.

Conclusion

The current study supported the view that osteotomy would result in positive changes in speech. While a positive effect on speech production was noticed, some subjects still had articulation errors post-surgically. Further investigation is needed for an explanation of an individual case who showed relapse one year post-operation. Modification of Lindblom et al.'s model is also needed to explain for the phenomenon of negative articulatory reorganization.

Speech therapy was recommended as the orthognathic effect was eliminated. However, the success of speech treatment depends on the person's motivation to improve their articulation and their perception of their speech (Vallino, 1987). Indeed, the pre-surgical questionnaire reflected that some subjects did not perceive that they had speech disorder even though they showed articulation errors. Hence, it was important to measure client's perception of their speech prior to speech therapy.

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Appendix I

Definition of malocclusion classification

Horizontal dental classifications

Class I malocclusion: normal anteropsterior relationship of jaws.

Class II malocclusion: The lower dental arch is posterior to the upper in one or both lateral segments, with lower first molar being distal to the upper first molar.

Class III malocclusion: The lower arch is anterior to the upper in one or both lateral segments, with lower first molar being mesial to upper first molar.

Vertical dental classifications

Open bite: The mandibular and maxillary teeth do not make incisal contact.

Overbite: The maxillary incisors overlap the mandibular incisors by more than one half.

Adapted from Vallino (1987) and Jablonski (1992)

Appendix II

Description of nature of distortion errors

I **Frontal distortions, Type I** – the tongue is protruded between the upper and lower teeth.

II **Frontal distortions, Type II** – the tongue tip is placed too far distally to the mandibular incisors while the tongue body is flattened, causing the air stream to be scattered.

III **Dentalization** – the tongue tip is placed against the superior surface of the upper or lower teeth (e.g. /s/ → [s̪])

IV **Lateralization** – the air stream is diverted off to one or both sides of the tongue.

V **Whistling** – high frequency sound created by the air passing between the tongue and alveolar ridge.

VI **Mandibular Movement** – the mandible is positioned anteriorly or shifts laterally.

VII **Labiodentalization** – the lower lip makes contact with the maxillary incisors.

VIII **Other:** included frication, e.g. /ts/ → [ts^{s}]; weak production (/f/ → [f̰] and bilabial fricative(e.g. /f/ → [ɸ]).

Adapted from Vallino (1987) and Whitehill (2001)

Appendix III

Terminology for orthognathic surgery

LeFort I: The upper jaw can be moved forward or backward, widened, narrowed, tilted.

LeFort II: It is more extensive than LeFort I and includes the upper portion of the nose and medial orbital wall.

Wunderer: Anterior maxillary osteotomy.

Schuchardt: Bilateral sagittal split osteotomy, using Schuchardt approach.

Hofer: Total mandibular subapical osteotomy. A circumvestibular incision is made from the retromolar area of one side of the mandibule to the opposite side

Segmental osteotomy: The horizontal, lower portion of mandible is moved forward.

Mandibular step: To correct mandibular arch width discrepancies.

Subsigmoid: Correct horizontal mandibular excess, obtain good arch and dental relationship by retruding the intact mandibular arch.

Sagittal split: Intraoral osteotomy of the ascending mandibular ramus and posterior body of the mandible in the sagittal plane.

Genioplasty: Vertical, horizontal, transversal reposition of chin

Adapted from Fonseca (2000)

Appendix IV

Table 3. Summary of ANOVA for effect of sibilant and period.

	df Effect	MS Effect	df Error	MS Error	F	*p*-level
Sibilant	3	169.28	87	14.84	0.45	0.00**
Period	2	284.52	58	23.56	0.35	0.00**
Sibilant X Period	6	9.92	174	12.80	0.29	0.18

** Significant at 0.01 level

Table 4. Summary of Tukey HSD test for effect of surgery on different periods.

	Pre-surgery	Post 3 months	Post 12 months
Pre-surgery	--	0.00**	0.00**
Post 3 months	0.00**	--	1.00
Post 12 months	0.00**	1.00	--

**Significant at 0.01 level

Table 5. Summary of Tukey HSD test for effect of surgery on individual sibilants.

Sibilants	Interaction: Sibilant X Period			Significant** ($p < 0.05$)
/s/	Pre-surgery	VS	Post 3 months	**
	Pre-surgery	VS	Post 12 months	**
	Post 3 months	VS	Post 12 months	
/f/	Pre-surgery	VS	Post 3 months	**
	Pre-surgery	VS	Post 12 months	**
	Post 3 months	VS	Post 12 months	
/ts/	Pre-surgery	VS	Post 3 months	
	Pre-surgery	VS	Post 12 months	
	Post 3 months	VS	Post 12 months	
/ts^h/	Pre-surgery	VS	Post 3 months	
	Pre-surgery	VS	Post 12 months	
	Post 3 months	VS	Post 12 months	

Appendix V

Table 6. Number of speech errors pre-surgery, 3 months and 12 months post-surgery.

Subject	Pre-surgery				Post 3 months				Post 12 months			
	/s/	/f/	/ts/	/tsʰ/	/s/	/f/	/ts/	/tsʰ/	/s/	/f/	/ts/	/tsʰ/
1.	0	0	0	0	0	11	0	0	0	0	0	0
2.	0	14	0	0	0	0	0	0	2	18	0	0
3.	10	17	13	12	0	0	0	0	0	8	0	0
4.	0	6	0	0	0	1	0	0	0	11	0	0
5.	10	1	0	2	0	6	0	0	0	3	0	0
6.	14	0	11	11	0	0	0	0	0	0	0	0
7.	6	0	12	2	0	0	0	0	0	0	0	0
8.	0	0	0	0	1	1	0	0	0	0	0	0
9.	0	16	0	0	0	0	0	0	0	0	0	0
10.	0	18	0	0	0	0	0	0	0	0	0	0
11.	6	18	0	0	0	0	0	0	0	0	0	0
12.	0	15	0	0	0	0	3	1	0	0	0	1
13.	1	0	0	0	0	0	0	0	0	0	0	0
14.	0	19	0	0	0	0	0	0	0	18	0	0
18.	0	19	0	0	0	0	0	0	0	5	0	0
20.	11	2	1	4	3	17	0	0	0	0	0	0
21.	0	5	0	0	0	20	0	0	0	0	0	0
22.	12	13	2	1	1	7	4	1	0	0	0	0
23.	19	0	16	17	0	0	0	0	0	0	0	1
24.	1	0	0	0	0	0	0	0	0	0	0	0
25.	0	17	0	0	0	0	0	0	0	0	0	0
26.	0	0	0	0	0	0	0	0	0	16	0	0
28.	12	0	11	0	0	0	0	0	0	0	0	0
29.	0	0	2	1	0	0	0	0	0	0	0	0

Note.

Subject 15, 16, 17, 19, 27 and 30 had no speech error pre-surgery, 3 months post-surgery and 12 months post-surgery.

Appendix VI

Table 8. Change in distortion pattern pre-surgery, post 3 months and post 12 months.

		Type 1	Type 2	Type 3	Type 4	Type 5	Type 8
/s/	Pre-surgery	--	71.43% (70/98)	18.37% (18/98)	10.20% (10/98)	--	--
	Post 3 months	--	--	100.00% (2/2)	--	--	--
	Post 12 months	--	100.00% (2/2)	--	--	--	--
/f/	Pre-surgery	--	--	--	--	90.56% (163/180)	9.44% (17/180)
	Post 3 months	--	--	--	--	60.32% (38/63)	39.68% (25/63)
	Post 12 months	--	--	--	--	100.00% (79/79)	--
/ts/	Pre-surgery	2.94% (1/68)	55.88% (38/68)	36.76% (25/68)	--	--	4.41% (3/68)
	Post 3 months	--	42.86% (3/7)	--	--	--	57.14% (4/7)
	Post 12 months	--	--	--	--	--	--
/ts^h/	Pre-surgery	2.00% (1/50)	90.00% (45/50)	4.00% (2/50)	--	--	4.00% (2/50)
	Post 3 months	--	50.00% (1/2)	--	--	--	50.00% (1/2)
	Post 12 months	--	100.00% (1/1)	--	--	--	--